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# Relationships among Observed Metal Concentrations, Criteria, and Benthic Community Structural Responses in 15 Streams

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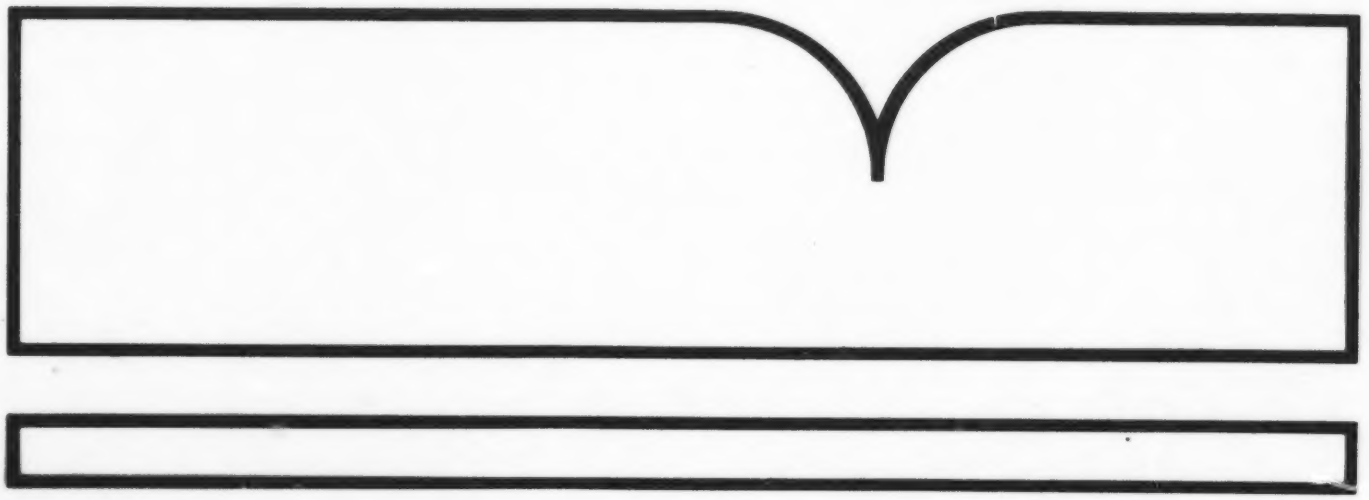

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JOURNAL ARTICLE

# Relationships among observed metal concentrations, criteria, and benthic community structural responses in 15 streams

T. W. LaPoint, S. M. Melancon, M. K. Morris

Water quality criteria for toxic substances published by the U. S. Environmental Protection Agency (EPA) are established to protect aquatic life and human health.[1] An aquatic life criterion specifies the concentration of metal, pesticide, or other toxicant below which ecosystem integrity is maintained. However most criteria are based on toxicity evidence from only a few sensitive aquatic species, such as *Daphnia magna, Pimephales promelas,* and *Salmo* spp. Single-species tests usually use organisms of uniform age and size and therefore lack the heterogeneous responses of a natural population.[2] Other factors that affect the natural ecosystem balance are not necessarily reproduced in the laboratory, such as nutrition, physiological interaction, substrate, current, and light.[3] Species interactions, such as predation or competition, are also primary regulating factors in an ecosystem.[4,5] In general, knowledge of the effect on a single species is necessary, but not sufficient, to predict changes in resident species populations in the aquatic ecosystem.

**Seasonal monitoring schemes should be required to determine if criteria are adequate or overprotective for aquatic communities.**

Recent studies confirm the limitations of using laboratory test results to predict effects in complex aquatic ecosystems. Roberts *et al.*[6] reported low toxicity for polychlorinated biphenyls (PCBs) in laboratory bioassays, and field studies revealed a decrease in invertebrate species diversity. Winner *et al.*[7] reported similarity in the benthic community response of two streams, one subjected to a single toxicant (copper) at relatively constant concentrations over a long period of time, and the other subjected to multiple toxicants (copper, chromium, and zinc) at higher and more variable concentrations. In both streams, control, polluted, and recovery zones were characterized by predictable and similar sequences of resident invertebrate species. Finally, Buikema and Cherry[8] presented an analysis of studies on 12 riverine ecosystems in which metal concentrations exceeded EPA water quality criteria, although biological parameters indicated a "healthy and diverse" community of organisms. Buikema and Cherry stated that, in general, ". . . the 1980 Water Quality Criteria for selected metals are too stringent and overprotective for aquatic life." Specifically, cadmium, copper, lead, and zinc criteria were frequently exceeded with no apparent effect on the resident biota; the gap between metal criteria and the health of the community was greatest in soft waters.

## STUDY RATIONALE

In 1980 the EPA Office of Water Regulations and Standards requested assistance from the Environmental Monitoring Systems Laboratory, Las Vegas, Nevada (EMSL-LV), in examining the validity of national water quality toxic metal criteria for protecting aquatic life. Specifically, assistance was requested in documenting water and biological quality in selected streams across the U. S. that receive toxic metals from mining, industrial, or municipal sewage treatment plant discharges.

Fifteen streams (Table 1 and Figure 1) were chosen to provide broad geographical representation and a wide range of watershed types and uses, pollution sources, water quality characteristics, biota, and habitats. The primary objectives were to document the concentration and distribution of toxic metals in selected streams, determine the biological state of receiving waters where the aquatic life criteria for metals were exceeded, report the extent to which criteria levels were exceeded, and develop explanatory hypotheses when healthy biota existed where criteria were exceeded. This paper summarizes the findings of 15 river studies from the 1980 survey (Table 1).

## EXPERIMENTAL

Each of the 15 rivers were intensively sampled one time between August and November, 1980. Specific methods for each of the 15 sites are provided in individual EPA reports.[9-23] Shown here are sampling methods and analyses common to all the surveys. Stations were established in each river to reflect control, impact, and recovery zones. Control stations were upstream from known discharge points. Impact stations were downstream from point source(s) in zones where the effluent and receiving waters were completely mixed. Recovery stations were downstream where resident biota seemed similar to that of the control zone.

Nutrients and metals sampled included all those listed in Table 2, although metals exceeding national criteria[1] were of

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16. ABSTRACT

Water quality criteria for toxic substances published by the U.S. Environmental Protection Agency (EPA) are established to protect aquatic life and human health. An aquatic life criterion specifies the concentration of metal, pesticide, or other toxicant below which ecosystem integrity is maintained. However, most criteria are based on toxicity evidence from only a few sensitive aquatic species, such as Daphnia magna, Pimephales promelas, and Salmo spp. Single-species tests usually use organisms of uniform age and size and therefore lack the heterogeneous responses of a natural population. Other factors that affect the natural ecosystem balance are not necessarily reproduced in the laboratory, such as nutrition, physiological interaction, substrate, current, and light. Species interactions such as predation or competition, are also primary regulating factors in an ecosystem. In general, knowledge of the effect on a single species is necessary, but not sufficient, to predict changes in resident species populations in the aquatic ecosystem.

17. KEY WORDS AND DOCUMENT ANALYSIS

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**Table 1—Rivers sampled during 1980 toxic metals survey, types of discharge, and metals exceeding U.S. EPA Acute Water Quality Criteria.**

| River number | Name | Longitude/latitude | Discharge type | Metals exceeding criteria | Ref |
|---|---|---|---|---|---|
| 01 | Prickly Pear Creek, MT | 46 22 40.0/112 01 40.0 | Mining | As, Cd, Cr, Cu, Ag, Zn | 9 |
| 02 | Silver Bow Creek, MT | 46 03 00.0/112 47 00.0 | Mining, POTW | As, Cd, Cr, Cu, Se, Zn | 10 |
| 03 | Slate River, CO | 38 52 40.0/106 58 40.0 | Mining, POTW | As, Cd, Cu, Se, Ag, Zn | 11 |
| 04 | White River, IN | 39 43 40.0/86 11 00.0 | Industrial, POTW | As, Cd, Cr | 12 |
| 05 | Red River, NM | 36 40 30.0/105 22 40.0 | Mining | As, Cd, Ag | 13 |
| 06 | Little Mississinewa River, IN | 40 11 30.0/84 50 00.0 | Industrial | As, Cd, Cr, Cu, Se | 14 |
| 07 | Mill Creek, OH | 40 20 00.0/83 26 40.0 | Industrial, POTW | As, Cd, Cr | 15 |
| 08 | Maple Creek, SC | 34 56 00.0/82 13 00.0 | Industrial, POTW | As, Cd, Cr, Cu, Ag, Zn | 16 |
| 09 | Cayadutta Creek, NY | 43 02 09.0/74 21 55.0 | POTW | Cr | 17 |
| 10 | Irwin Creek, NC | 35 14 40.0/80 51 00.0 | POTW | Cd, Cr, Cu, Pb, Ag, Zn | 18 |
| 11 | Blackstone River, MA | 42 15 00.0/71 52 30.0 | Industrial, POTW | Cd, Cr, Cu, Pb, Se, Ag | 19 |
| 12 | Cedar Creek, GA | 34 20 20.0/82 56 00.0 | POTW | Cr, Cu, Pb, Ag, Zn | 20 |
| 13 | Bird Creek, OK | 36 28 36.0/96 05 00.0 | POTW | Cd, Ag | 21 |
| 14 | Tar Creek, OK | 37 01 00.0/94 51 00.0 | Mining | Cd, Cr, Ag, Zn | 22 |
| 15 | Leon Creek, TX | 29 23 30.0/98 36 30.0 | Industrial, POTW | Cd, Cr, Se, Ag | 23 |

particular interest. Triplicate grab samples were collected mid-depth at each river site, preserved appropriately,[24,25] and shipped to the laboratory for analysis. Nutrients were analyzed at EMSL-LV with an autoanalyzer. Temporal variation in water quality was measured by collecting individual water samples over 3-hour intervals for periods up to 72 hours. Metal concentrations were measured using inductively coupled plasma emission spectroscopy (ICP) at UCLA's Laboratory of Biomedical and Environmental Science. ICP was used because it is able to analyze many metals simultaneously.

At each station within each river, three to five replicate macroinvertebrate samples were collected, primarily using a kick method developed at EMSL-LV.[26] Kick samples were standardized by holding a 30-mesh triangular dip net in the water in front of the investigator for 30 seconds while traveling downstream, vigorously kicking the substrate (approximately 3 $m^2$ areal coverage). In small streams, or those with larger substrate that made kick sampling inefficient, we used a portable invertebrate box sampler (PIBS).[27] The net on the PIBS (0.1 $m^2$ areal coverage) was also constructed of the same cloth as that for the dip net.

**Figure 1—Study streams, toxic metals project, 1980.**

Replicate samples were taken from each zone in all rivers, preserved in approximately 10% formalin, and returned to the University of Nevada, Las Vegas for processing. All collected invertebrates were generally keyed to species except oligochaetes and chironomids which were only identified to family and subfamily, respectively.

## RESULTS

Each of the 15 rivers sampled in 1980 can be put into one of three general categories, according to invertebrate response and chemical characteristics: rivers which had primarily nutrient pollution problems, those polluted primarily by metals, and those with influencing factors in addition to metal or nutrient problems. These categories are graphically illustrated in Figure 2.

**Nutrient impacted.** Six of the 15 rivers sampled in 1980 were primarily nutrient polluted (Figure 2). Two were also polluted with metals and two were influenced by other factors.

**Table 2—Water quality chemical parameters collected during toxic metals survey, 1980.**

A. **Technicon Auto Analyzer (mg/L)**
- Hydrolyzable phosphorus
- Orthophosphate
- Kjeldahl nitrogen
- Ammonia nitrogen ($NH_3$-N)
- Nitrate-Nitrate—nitrogen
- Alkalinity

B. **In Situ Parameters**
- Dissolved oxygen (mg/L)
- pH (su)
- Temperature (°C)
- Conductivity (μmho)
- Turbidity (NTU)
- Chlorine (mg/L)

C. **Metals—ICP[a] (μg/L)**
- Al, As, Cd, Cr, Cu, Fe, Pb, Mn, Ni, Se, Ag, Zn, Ca, Mg
- Total recoverable
- Filtered through 0.45 μm

D. **Additional Parameters (mg/L)**
- Total nonfiltered residues
- Cyanide
- Total organic carbon

[a] ICP = Inductively Coupled Plasma emission spectroscopy.

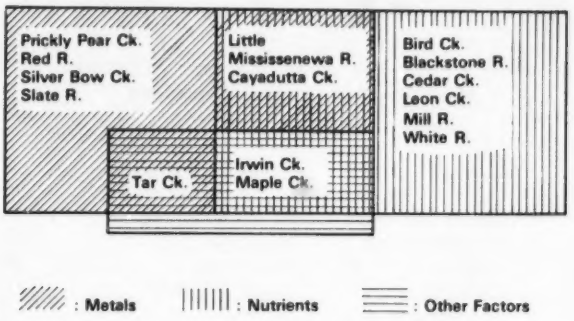



**Figure 2—Streams and rivers grouped according to their primary inputs. Slanted bars indicate primarily metals; vertical bars indicate primarily nutrient problems; horizontal bars indicate unusual or anomalous pollutant input.**

Invertebrate populations found within the impact zones of each river were classically characteristic of organically enriched streams.[28-32] Diverse upstream communities were replaced by high relative abundances of Chironominae midges and oligochaete (Tubificidae) worms. These taxonomic groups may also indicate metal pollution to a stream.[7,33] However many rivers in this category had low water hardness (in Cedar Creek the hardness ranged from 9–21 mg/L $CaCO_3$). In such cases, ambient metal concentrations exceeded calculated acute criteria although they were barely above the detection limits. For example, mean total copper concentrations in the Cedar Creek control and impact zones (19.2 $\mu$g/L and 19.8 $\mu$g/L, respectively) were above calculated criteria (2 to 5 $\mu$g/L), but barely above the copper detection limit (11 $\mu$g/L).

Streams within this category consistently had statistically greater ($\alpha$= 0.05) concentrations of nutrients ($NH_3$-N, Kjeldahl-N, total P, ortho-P, $NO_2 + NO_3$-N) and of total residues within impact and recovery zones (Figure 3) than in control zone sites. Often, impact and recovery zone concentrations varied more than two orders of magnitude over control zone levels. Dissolved oxygen often declined dramatically (Figure 3). Thus although some metals were in excess of acute water quality criteria for these rivers (Figure 4), the evidence suggests that organic and nutrient contributions were more causally related to the overall invertebrate community structure than were the metals.

**Metal impacted.** Pollution impacts in four of the 15 streams were attributed almost solely to metals (Figure 2). Two streams, Cayadutta Creek and Little Mississinewa River, also received considerable organic and nutrient enrichment. Tar Creek was influenced by other factors. All the streams that received mine drainage waters (Table 1) showed some evidence of metal pollution. However to find a simple metals-only pollution problem in streams affected by industrial or municipal discharges is rare.

Overall, benthic community responses to elevated metal concentrations were less consistent than those found in rivers subject to nutrient enrichment. Control and recovery zones within these rivers generally had statistically higher species richness and greater relative invertebrate abundance than did the impact zones. However specific community structural responses varied among rivers. For example, in Prickly Pear Creek community response to the mining impact involved a significant reduction in the number of taxa (Figure 5) but with all major invertebrate orders still represented throughout the river. Conversely, in Slate River the maximum number of taxa occurred in the second impact zone station with a decrease in diversity within the recovery zone (Figure 6) and a predominance of Orthocladiinae midges.

**Other influences.** Both Irwin Creek and Maple Creek overlap with the nutrient-enriched group (Figure 2). Irwin Creek is included here because substrate characteristics within the impact zone were sufficiently different from the upstream control zone to potentially alter invertebrate populations. Maple Creek is included because field biologists reported an industrial spill had occurred 2 weeks before sampling; thus the invertebrate populations might reflect this episodic event rather than trends typical of the stream at other times.

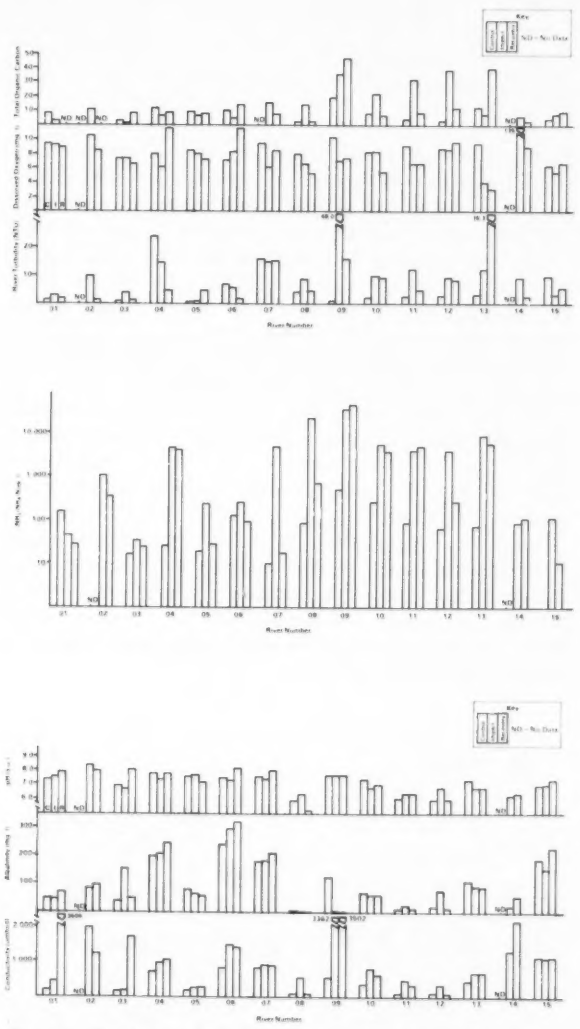


**Figure 3—Standard water chemistry and nutrient values for 15 streams, toxic metals project, 1980. For each stream (designated by river number in Table 1), control, impact, and recovery zone stations are labeled C, I, and R, respectively.**

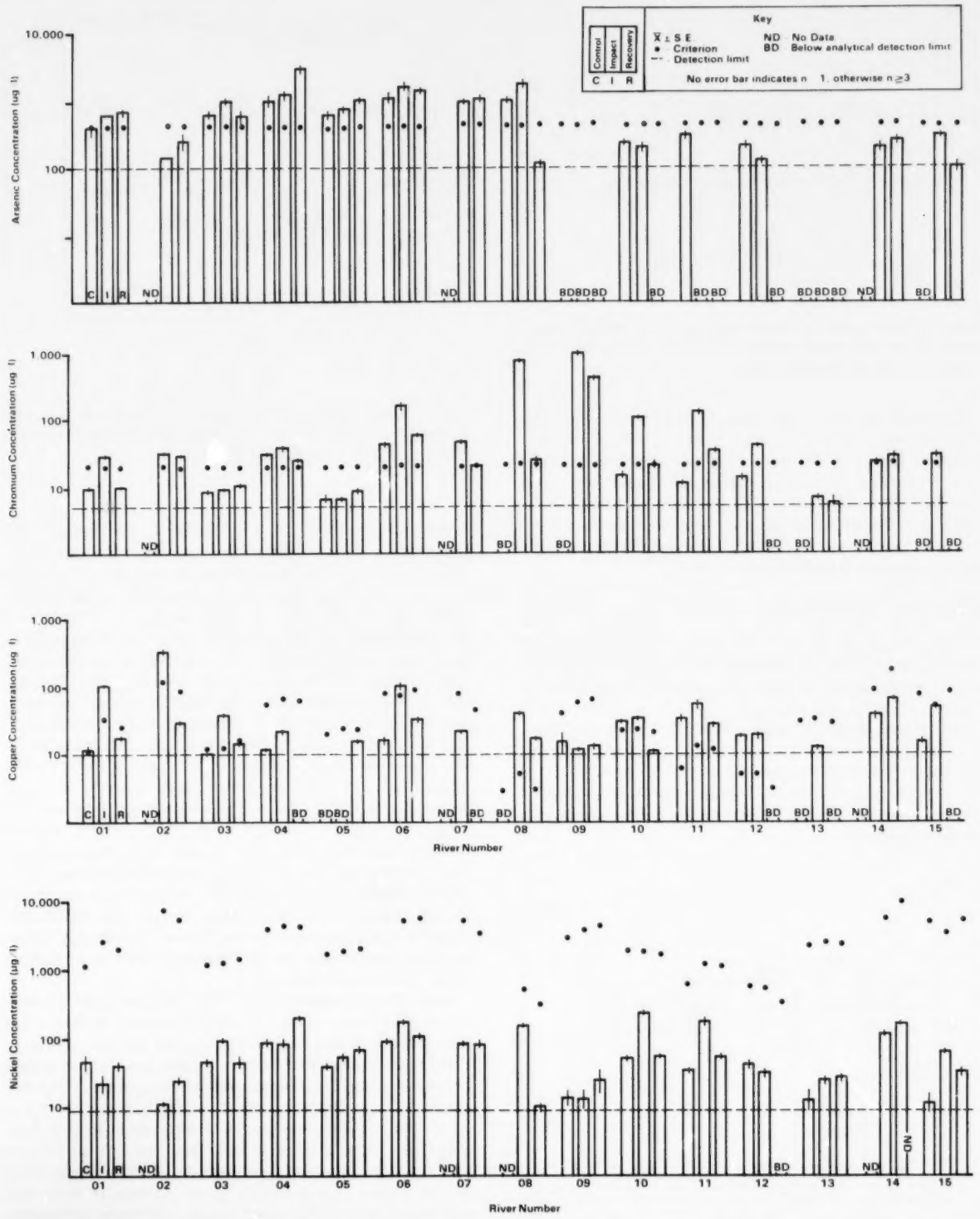



**Figure 4—Metal concentrations for 15 streams, toxic metals project, 1980. For each stream (designated by river number in Table 1), control, impact, and recovery zone stations are labeled C, I, and R, respectively.**

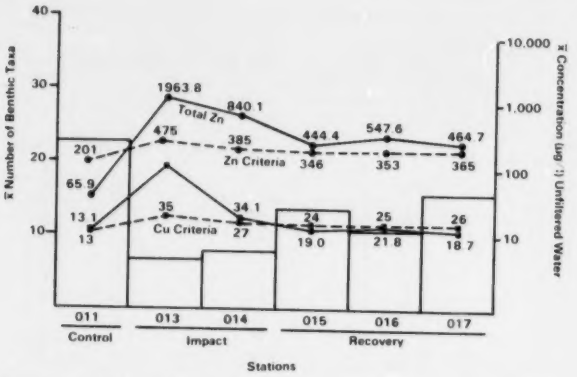



**Figure 5—Mean number of benthic taxa, mean total ambient concentrations of zinc and copper, and EPA acute zinc and copper criteria, Prickly Pear Creek, Montana, 1980.**

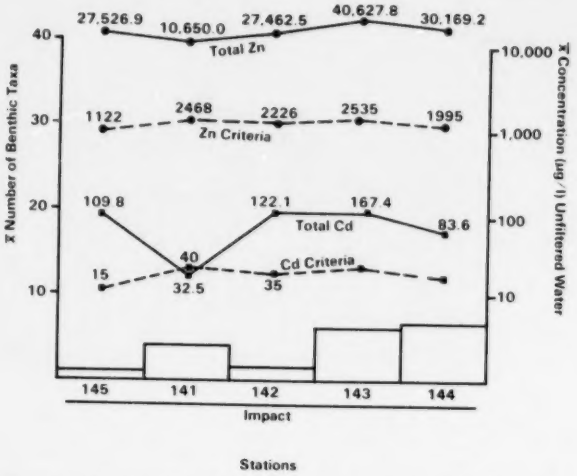



**Figure 7—Mean number of benthic taxa, mean total ambient concentrations of cadmium and zinc, and EPA acute cadmium and zinc criteria, Tar Creek, Oklahoma, 1980.**

Tar Creek (Figure 7) was characterized by extremely high water hardness (451–1205 mg/L $CaCO_3$), which mitigates biological toxicity of elevated metal concentrations.[34–38] Resident invertebrate populations of this ephemeral stream were typical of a lentic environment,[39] albeit a restricted one. Thus flow and substrate factors may have affected the taxonomic distributions observed in Tar Creek invertebrate communities, perhaps as much as metal concentrations.

## SPECIFIC EXAMPLES

Study results for all 15 rivers (Table 1) are reported in unpublished response reports prepared by the EPA EMSL-LV. In this section results for the six rivers that best illustrate the program objectives are described.

**Prickly Pear Creek, Montana (River 01).** The metals originally of interest here were copper and zinc. Results indicated that criteria levels for copper and zinc were exceeded in the impact zone (Figures 4 and 5). Copper levels declined to below criteria in the recovery zone, but zinc levels remained slightly elevated (Figure 5).

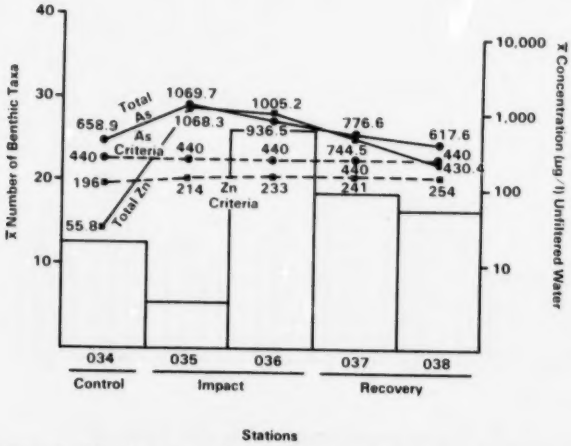
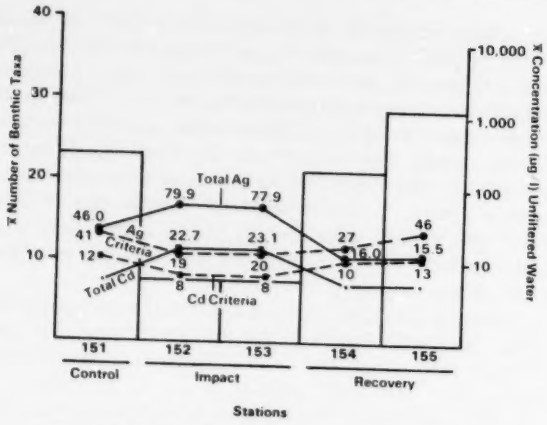



**Figure 6—Mean number of benthic taxa, mean total ambient concentrations of arsenic and zinc, and EPA acute arsenic and zinc criteria, Slate River, Colorado, 1980.**

Benthic invertebrate samples are usually non-normally distributed, with heteroscedastic variances; hence the appropriate statistical tests involve distribution-free analyses of ranks. In Prickly Pear Creek, the benthic community response was similar to that reported in other studies. The number of invertebrate taxa and of individuals per $m^2$ decreased in direct proportion to the increased concentration of metals. In the recovery zone, 13 km downstream from the effluent source, the numbers of taxa and of individuals increased as metal concentrations decreased. A Spearman rank correlation[40,41] performed on the total number of taxa collected versus copper and zinc concentrations yielded $r_s = -1.00$ and $r_s = -0.94$, respectively. The numbers of individuals collected were also negatively correlated with zinc and copper ($r_s$ −0.80 for zinc, −1.00 for copper). However correlations are not used to establish cause and effect; they are used as a measure of how closely linked are two co-varying parameters. Further direct experimentation would be necessary to determine any causal linkage between suites of variables. Arsenic (and silver) concentrations also exceeded criteria (Figure 4) at all sites, but nc statistical relationship to the observed variance in benthic invertebrates was demonstrated.

**Slate River, Colorado (River 03).** The first impact station within Slate River showed a marked decrease in both mean total number of taxa (Figure 6) and mean number of invertebrates relative to all other stations. A Spearman rank correlation between the number of taxa collected versus arsenic and zinc concentrations yielded correlation coefficients of −0.70 and −1.00, respectively. Arsenic values were, as in Prickly Pear, above the criterion value in all zones, but seemed to have little influence on macroinvertebrate distribution. In the recovery zone, there was a shift to fewer numbers of taxa, with dominance by Orthocladiinae midges. Cadmium and copper were also above their respective criteria levels in both the impact and recovery zones (Figure 4).

**Leon Creek, Texas (River 15).** Cadmium and chromium exceeded criteria in the Leon Creek impact zone (Figures 4




*Nondetectable (7.5 ug/l = cadmium detection limit)

**Figure 8—Mean number of benthic taxa, mean total ambient concentrations of silver and cadmium, and EPA acute silver and cadmium, Leon Creek, Texas, 1980.**

and 8), and silver remained above its criterion in the control and impact zones. The Spearman rank correlation between mean number of taxa and cadmium was −0.87. However nutrient inputs in Leon Creek during 1980 (Figure 3) seemed to have overwhelmed most observable toxic effects of metals on the resident biota. Ammonia, total phosphorus, and Kjeldahl nitrogen all increased in and downstream from the impact zone, and dissolved oxygen decreased. The invertebrate fauna reflected these nutrient inputs in two ways: community composition shifted to 95% oligochaete worms in the impact zone, and the mean total number of invertebrates collected was significantly higher than in either the control or recovery zones.

**Cayadutta Creek, New York (River 09).** Chromium was the sole metal in excess of its criterion within Cayadutta Creek (Figures 4 and 9). Chromium concentrations increased downstream from the wastewater treatment plant discharge, and remained above the criterion at all remaining sample sites downstream. Ammonia and Kjeldahl nitrogen increased downstream from the impact zone (Figure 3) and dissolved oxygen decreased.

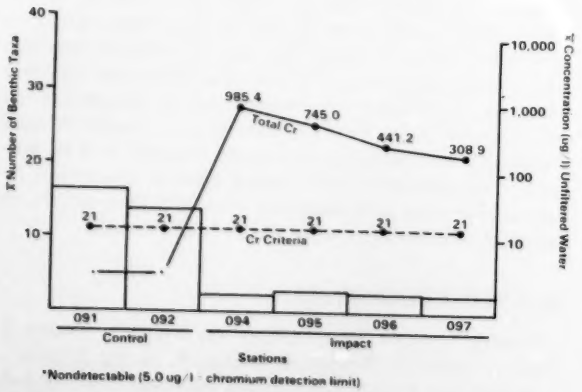
Because of elevated nutrient and metal concentrations, and because of the invertebrate community response, no recovery zone was designated for this study site. The macroinvertebrate fauna changed from caddisflies and some Dipteran species in the control zone to complete dominance (100% in several samples) by Diptera, primarily genus *Chironomus,* in the extended impact zone.

**Irwin Creek, North Carolina (River 10) and Tar Creek, Oklahoma (River 14).** These streams demonstrate the unexpected problems that can develop in a monitoring project. In Irwin Creek metal inputs seemed to be diffuse. Lead and cadmium exceeded criteria only in the control zone. Copper, silver, and chromium exceeded criteria in both control and impact zones (Figures 4 and 10). The mean number of taxa collected were negatively correlated to zinc and chromium concentrations ($r_s$ = −0.66 and −0.7, respectively). However the correlations were weaker than in other streams surveyed. The invertebrate fauna did not seem to reflect changes, either in nutrients or in metal concentrations; Chironominae and Orthocladiinae midges were very common throughout the stream and no trends were obvious in the remaining taxa.

A confusing variable in Tar Creek was diverse substrates which varied in composition and substrate size between the control and impact zones. Differences in the fauna would be expected from substrate differences alone. In both Tar and Irwin Creeks, substrate may have had a dominant influence on invertebrate behavior and metal adsorption, as well as influencing nutrient availability.

## DISCUSSION AND CONCLUSIONS

Herricks and Cairns[42] concluded that "descriptive approaches are essential in biomonitoring programs," for "only through careful description can one characterize the community." However an analytical approach is also necessary if one wishes to determine cause and effect relationships. The EPA toxic metals program, descriptive by design, was intended to examine




*Nondetectable (5.0 ug/l = chromium detection limit)

**Figure 9—Mean number of benthic taxa, mean ambient concentrations of chromium, and EPA acute chromium criteria, Cayadutta Creek, New York, 1980.**

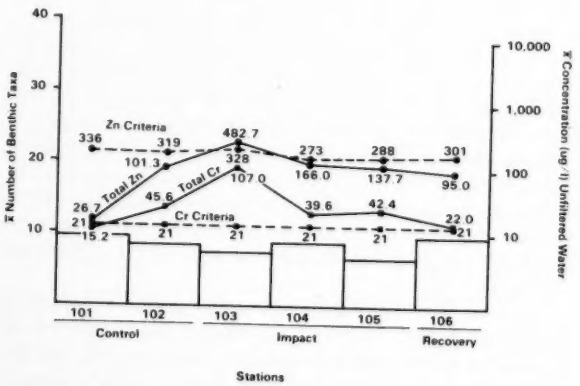



**Figure 10—Mean number of benthic taxa, mean total ambient concentrations of zinc and chromium, and EPA acute zinc and chromium criteria, Irwin Creek, North Carolina, 1980.**

the invertebrate community structure of streams with metal concentrations in excess of criteria.

Generally, our study supports the supposition, and increasing literature evidence, that benthic fauna can reflect changes in water quality. Support for such a biomonitoring approach is provided by an increasing number of studies.[43-46] However the responses of several invertebrate communities in our study, Tar Creek, Figure 7, and Irwin Creek, Figure 10, demonstrate that community structural measures such as species richness, evenness, and diversity will not always—under finite time and funding limits—yield useful information about the biological integrity of the receiving stream. Species evenness and diversity are derived variables; often the sampling distributions and variances for these variables are, at best, poorly known.[41,47,48] We have emphasized species richness because it is a simple, direct measure of community structure. The coefficients of variation for the mean number of taxa collected per station (based on 5 replicates at each station) varied from 8% to as much as 120% over all 15 rivers; generally, however, the coefficients of variation were within 20 to 50% of the mean.

Particularly in streams receiving complex effluents, onsite bioassays are necessary and are beginning to be successfully applied in management and pollution control studies.[46,49,50] Onsite bioassays incorporate static-replacement and flow-through dilution chambers, each chamber with an equal number of individuals of a resident aquatic species. Each bioassay test performed onsite measures acute toxicity using effluent water as the toxicant; the toxicant is dosed at various concentrations into test chambers containing water collected upstream from the effluent source, usually from the control station. Organisms used in these bioassays are resident in the control station of the particular river in question. Hence test organisms used in these bioassays have included insects such as mayflies and midges, crustaceans (*Daphnia* spp., amphipods), and fish of various species.

Combining biomonitoring and bioassays is necessary to understand whether criteria are over- or underprotective. Laboratory-derived $LC_{50}$s and $EC_{50}$s used as indices of toxic effects are quite appropriate for species subject to a given pollutant or series of pollutants.[51,52] The difficulty arises in choosing laboratory strains of species (or groups) sensitive enough to indicate a conservative, safe, metal concentration value for a stream, given ambient flow, temperature, and substrate conditions. Onsite bioassay results reflect acute effluent toxicity under ambient field conditions. Lethality will be a function not only of effluent toxicity, but of diel variation in both physical and chemical water quality parameters in the control zone. Furthermore the use of onsite bioassays in conjunction with biomonitoring can indicate the presence of effluent toxicity even if confounding effects (such as substrate composition differences among stations, flow differences, and differences in nutrient concentrations) diminish the value of using community structural parameters to measure the effect of the effluent on the river.

Thus for the relatively simple metal pollution problems found in a minority of rivers, the resident fauna responds in a predictable and indicative manner, which overall may be more sensitive than any single species tests. As the pollutant chemistry becomes more complex, however, or as the physical habitat exerts an increasingly strong role in determining which species can exist,[53] community structural responses become less readily predictable. As found in Irwin, Tar, and Maple creeks, physical effects (including current velocity and correlated substrate particle size composition) and ambient nutrient concentrations seem to overwhelm the effects of metals on the resident fauna. In Irwin and Maple creeks, ammonia-nitrogen, nitrate-nitrogen, total phosphorus, and total organic carbon increased to high concentrations downstream from the control stations (Figure 3). The invertebrate communities of these rivers were strongly dominated by midges (*Chironomus* spp.) and by oligochaete worms; these taxa are commonly associated with nutrient-rich waters.[53]

Ephemeral flow characteristics and widely varying substrate composition were factors in the low mean number of taxa collected throughout Tar Creek (Figure 7). Among-station comparisons were made difficult in Tar Creek because of extremely high metal concentrations at all stations (Figure 4). Variation in metal concentrations is not reflected by changes in benthic community composition of Tar Creek.

In rivers subject to variable substrate regimes, variable (complex) effluents, or some combination of these, seasonal variation in species abundances and in physical and chemical parameters such as discharge, temperature, and suspended solids must be measured. Seasonal variation in physical and chemical parameters in rivers directly affects faunal composition, food availability, and the number of species present.[54] For instance, the mean number of species collected in a study of Salmon River[54] increased in all sites from winter to summer. However invertebrate abundance (number/$m^2$) decreased during the same period at three out of four stations. Without this information one cannot determine if an established criterion is adequate for any given river for any given season.

On the basis of a number of studies,[7,8,54,55] we suggest that a seasonal monitoring regime, in which the sampling schedule is based on critical flow periods, be required to assess the toxicity of effluent discharges to the aquatic fauna. In western U. S. rivers, the sampling schedule could comprise three periods: late winter-early spring (before snowmelt runoff), spring-early summer (post snowmelt runoff), and autumn-early winter (base flow conditions). This sampling regime would vary according to differing annual hydrographs, but should still encompass critical periods of time for the aquatic fauna. We recognize that for some rivers, critical flow periods (such as summer low-flow) for resident biota may be already known from extensive past studies. In these cases, economic considerations may outweigh the need for seasonal sampling, and biomonitoring can be limited to the critical time. However this level of background knowledge may be exceptional. As Winner *et al.*[7] state, "It is necessary to take multiple samples throughout the seasons if community structure is to be adequately characterized." Only known seasonal invertebrate responses will allow us to determine whether a given criterion is adequate or overprotective for aquatic communities.

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